Orion On-Orbit Inspection Capability Study

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NASA has been directed to build a Multipurpose Crew Vehicle capable of carrying humans beyond low-Earth orbit and conducting operations in low-Earth orbit. The Orion spacecraft development is anticipated to have high applicability to this project. Service in low-Earth orbit may require the vehicle to be docked to the International Space Station (ISS) for several weeks. During this time, it will be exposed to micrometeoroids and orbital debris (MMOD), which can potentially cause critical damage to the vehicle with respect to reentry heating. Understanding the criticality of damage will depend on effective on-orbit inspection of the vehicle. In 2008, the Orion Project tasked Johnson Space Center's Image Science and Analysis Laboratory (ISAL) to study the ability to inspect the Orion thermal protection system while docked to the ISS. The findings of the study will have direct applicability to the Multipurpose Crew Vehicle.

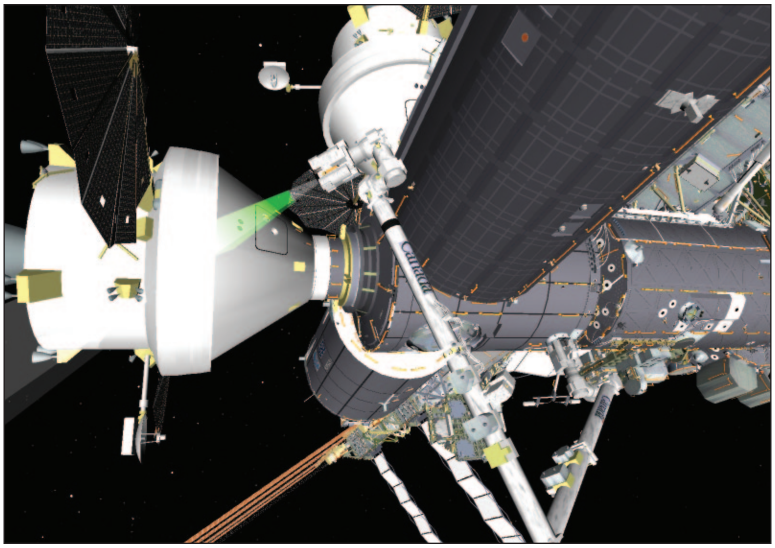

Fig. 1. *Snapshot of full-surface survey of the Orion Crew Module docked at International Space Station Node 2 Forward using Space Station Remote Manipulator System Latching End Effector camera.*

Specifically, ISAL was directed to explore the effectiveness of currently space-qualified sensors as inspection sensors for Orion docked to the ISS. At the same time, as part of their risk analyses, Orion Project personnel estimated the likelihood of critical MMOD strikes to the vehicle and has assumed that on-orbit inspections can be 95% effective in finding and determining the criticality of any such MMOD damage. For an Orion spacecraft, the surfaces of particular interest are the backshell and forward bay cover, due to their representing large components in the overall MMOD-based risk to crew safety and mission success. These surfaces are composed of tiles that are similar to the black thermal protection system tiles on the space shuttle. Critical damage to such tiles from MMOD strikes can result in damage cavities whose observable entry holes are as small as a quarter inch in diameter.

While NASA has placed a major emphasis on examining the utility of existing space-qualified sensors in the detection and characterization of MMOD damage cavities within thermal protection system tiles, the space agency has examined other sensors as well. All of the sensors examined by ISAL as candidates for on-orbit thermal protection system inspection have been non-penetrating two-dimensional (2-D) sensors (i.e., various cameras) and inherently three-dimensional (3-D) sensors (e.g., the Laser Camera System—currently space-qualified—and the Mold Impression Laser Tool). Other organizations have collected data from penetrating sensors, especially x-ray and millimeter-wave, but such sensing technology

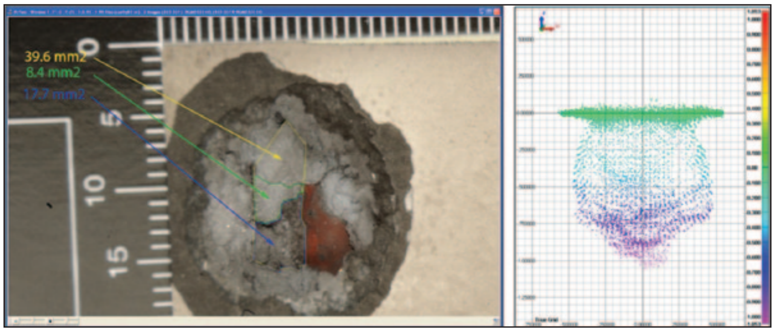

Fig. 2. *High-resolution digital image from stereo pair (left) and Laser Camera System three-dimensional point cloud elevation view (right) of hypervelocity impacted Orion thermal protection system tile are examples of potential focused-inspection sensor products.*

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has been outside the area of expertise for ISAL to date. Non-penetrating sensors have the advantage of high resolution and strong surface contrast as compared to penetrating sensors. The latter have the advantage of not requiring unobstructed lines of sight to structural damage. The attractiveness of space-qualified sensors is that they are known to be robust to launch acceleration and vibration, space radiation, and poor cooling from the lack of atmospheric convection. Space-qualified hardware generally has also (but not always) been the product of assembling reliable, high-quality components for which an expectation for long on-orbit operating life is justified.

Based on extensive experience with space shuttle on-orbit inspections, ISAL assumed that Orion inspections would consist of two major operations—the initial full-surface survey (figure 1) and close-range focused inspection (figure 2) for any suspected damage found during the initial survey. The full-surface survey is expected to be accomplished using a camera positioned by the ISS Space Station Remote Manipulator System over comprehensive scan trajectories. The focused inspections are expected to require both cameras and 3-D sensors as well as visible-band and, possibly, ultraviolet illumination, which has been seen to cause fluorescence in material underlying the tile, greatly enhancing the possibility of determining full tile penetration (figure 3). Focused inspections may also benefit later from penetrating sensors as technology allows. The survey cameras may be the Mobile Servicing System cameras already at each end of the Space Station Remote Manipulator System (and also positioned on a robotic attachment called Dextre), or another camera with greater resolution and/or greater robustness to varied lighting such as the Laser Dynamic Range Imager, a survey-type sensor used in space shuttle inspections. Focused-inspection sensors may require six degrees of freedom in positioning to ensure needed proximity and view angles, and will most likely need to be attachable to the "arms" of Dextre (shown in figure 4).

ISAL conducted various subjective tests using data collected by cameras and 3-D sensors to try to estimate inspection effectiveness using that hardware. The testing was designed to represent both an initial survey and focused inspection as described above. Probability of detection for the survey portion of the inspection has been estimated to exceed 95%, especially if redundant screening teams are employed. Although results using 2-D and 3-D non-penetrating sensors are encouraging, further testing will be required to determine focused-inspection effectiveness—and therefore overall inspection effectiveness—and whether penetrating sensors will also be needed. Testing to date shows that focused-inspection effectiveness will not only be dependent on sensors selection and deployment, but also on a ground process that draws on the discernment of structural experts.

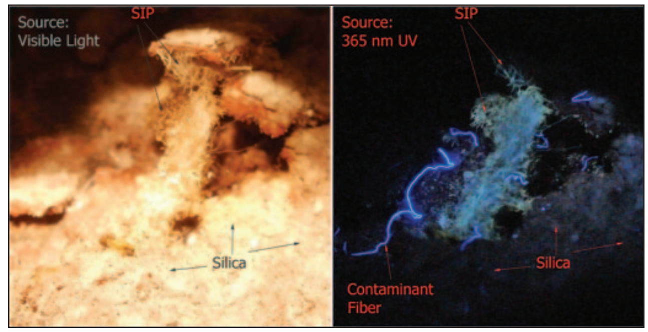

Fig. 3. *High-resolution digital image pair showing enhanced detectability of strain isolation pad material under ultraviolet illumination (right) as compared to visible-band illumination (left). Detection of exposed strain isolation pad (which will underlie tile on the Multipurpose Crew Vehicle) is an excellent indicator of full-tile penetration.*

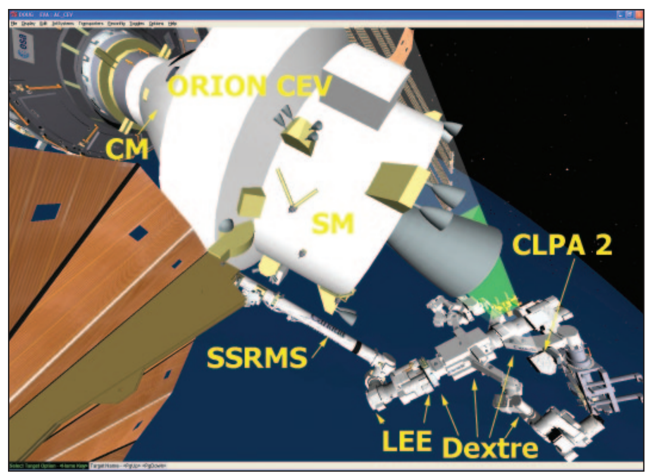

Fig. 4. *Dextre, on the Space Station Remote Manipulator System, provides additional reach and potential sensor positioning capability.*